(12) UK Patent Application (19) GB (11) 2 076 176 A

(21) Application No 8111411
(22) Date of filing 10 Apr 1981
(30) Priority data
(31) 80/16517
(32) 19 May 1980
(33) United Kingdom (GB)
(43) Application published 25 Nov 1981
(51) INT CL³ G02B 21/00//27/40
(52) Domestic classification G2J 8X
(56) Documents cited GB 2024445A
(58) Field of search G2J

(71) Applicant
Vickers Limited,
Vickers House, P.O. Box 177, Millbank Tower, Millbank, London SW1P 4RA

(72) Inventor
Francis Hughes Smith

(74) Agent
Haseltine Lake & Co.,
Hazlitt House, 28 Southampton Buildings, Chancery Lane, London WC2A 1AT, England

(54) Focusing Optical Apparatus

(57) An optical viewing apparatus and method is disclosed having improved focusing, in which two beams of light, which are mutually inclined at a fixed angle, are converted in the vicinity of a reflective viewed surface, and the relative distance between the apparatus and the surface is adjusted until the beams coincide at the surface.

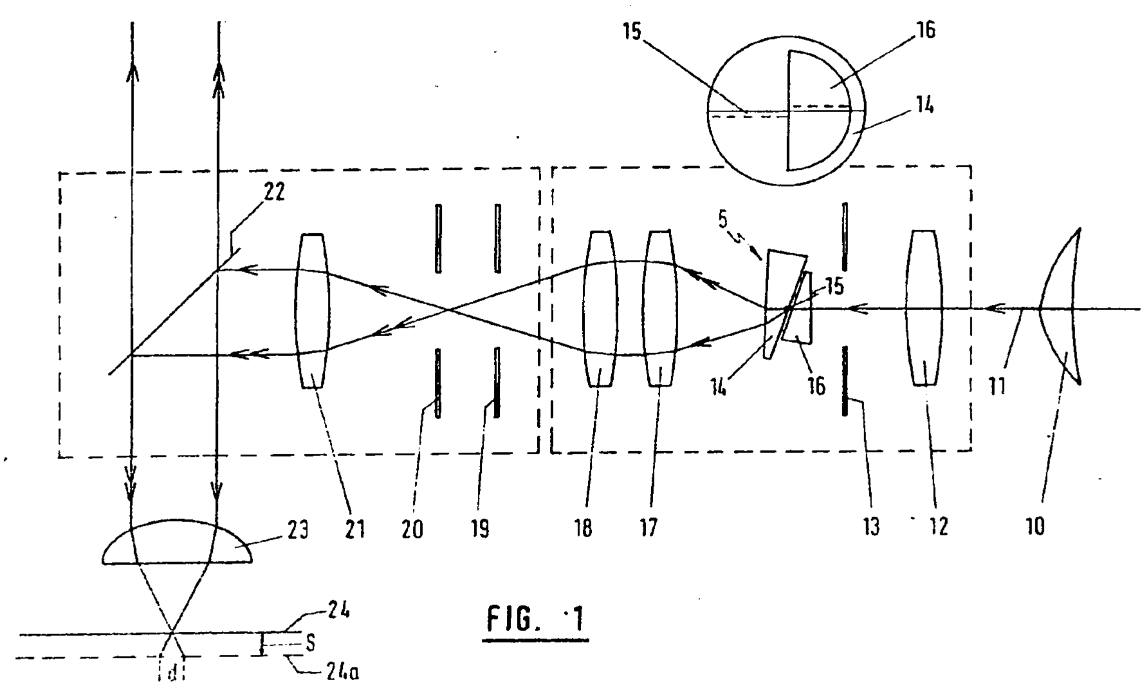

FIG. 1

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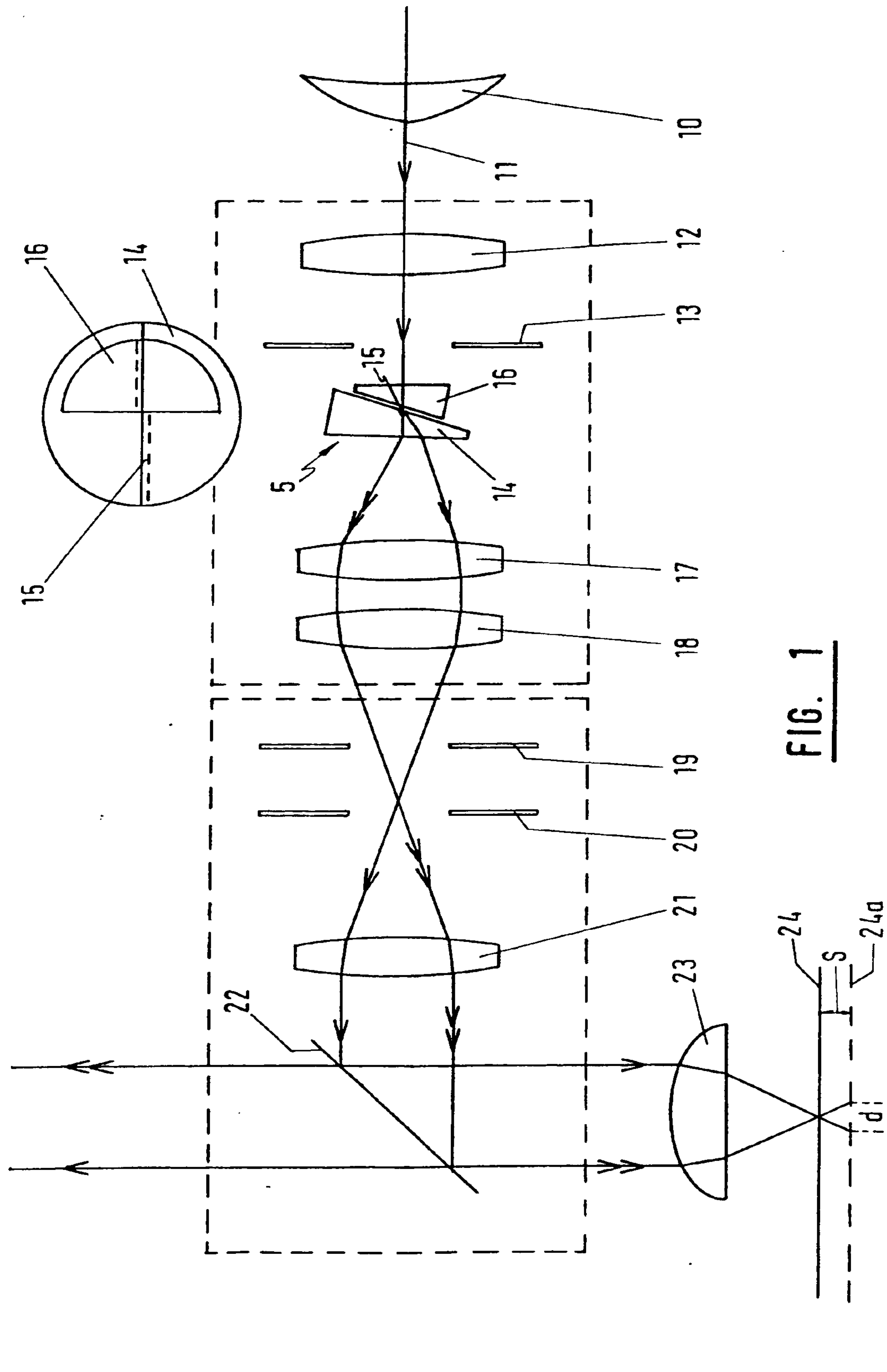

FIG. 1

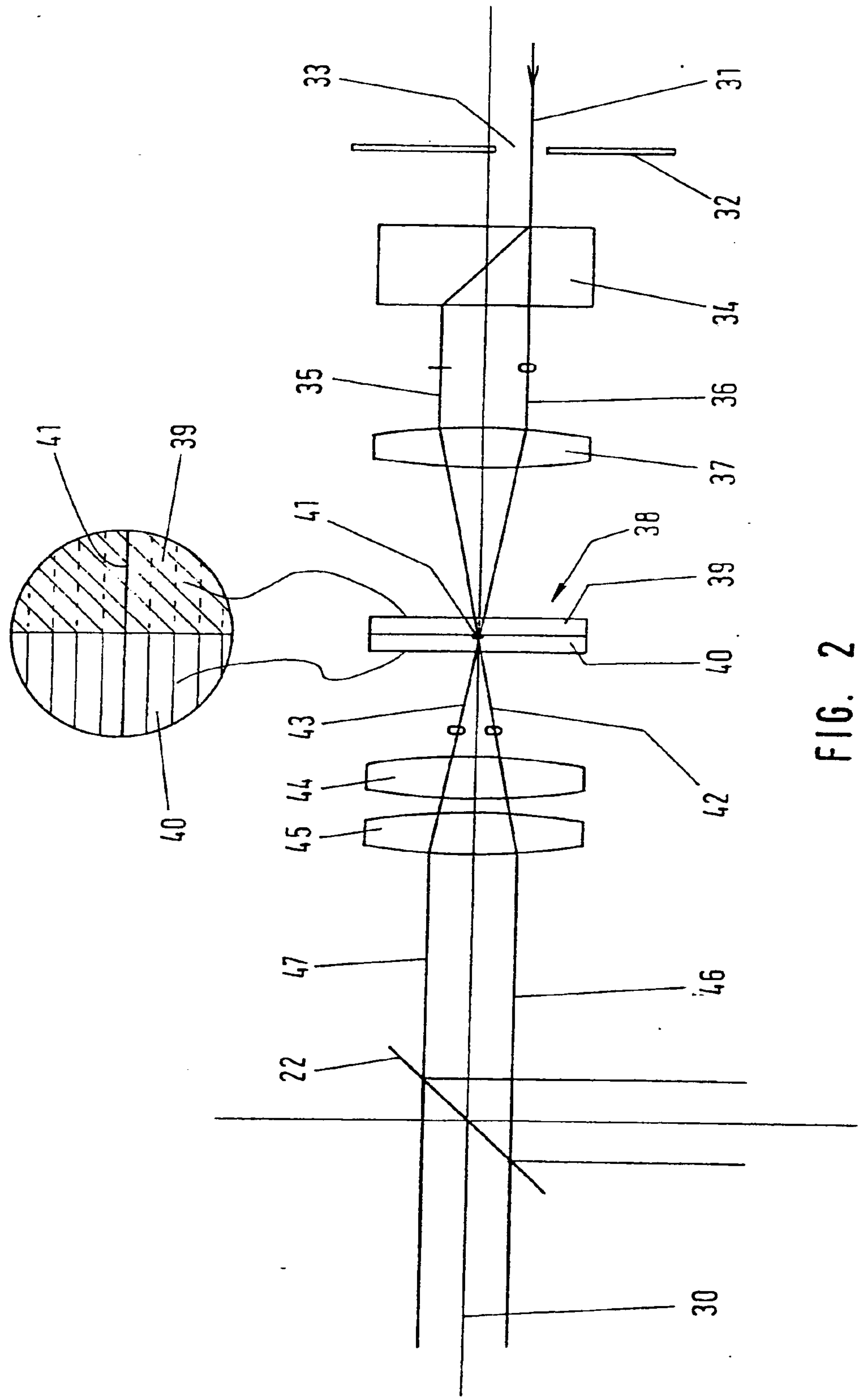

FIG. 2

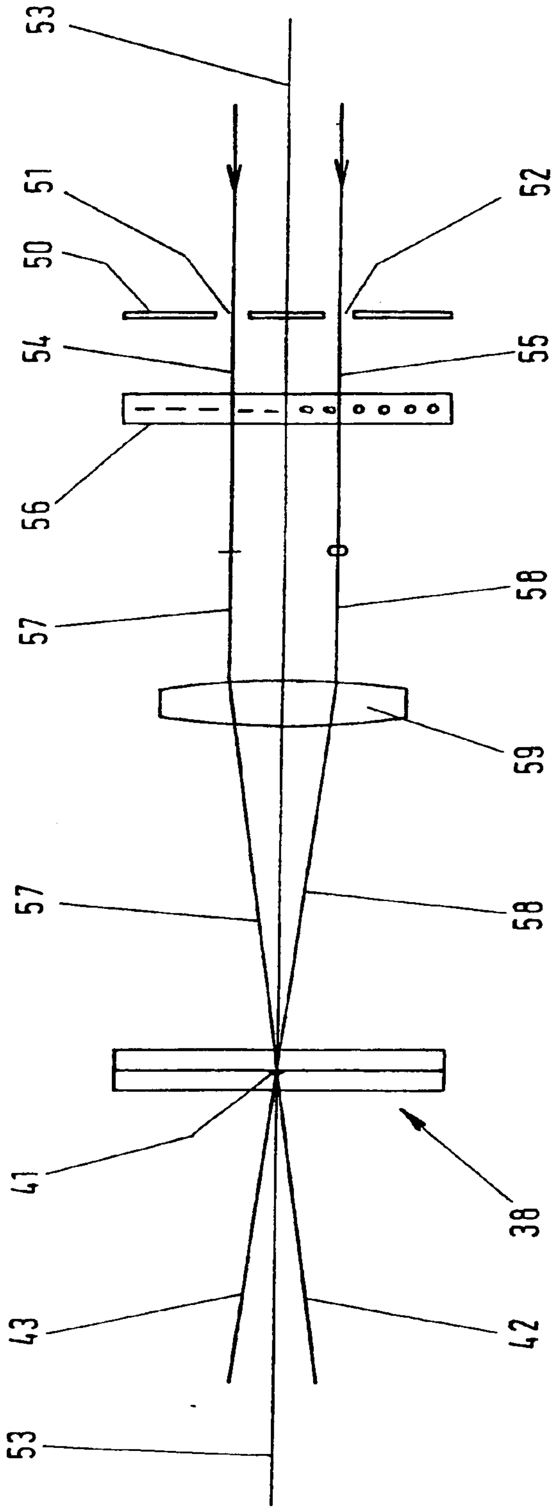

FIG. 3

SPECIFICATION
Focusing of Optical Viewing Apparatus

This invention relates to the focusing of optical viewing apparatus, and is particularly although not exclusively concerned with enabling optical microscopes to be focused upon reflecting surfaces more precisely than is currently possible, without recourse to complex photo-electric instrumentation.

Microscopes are frequently used for the measurement of small features on or intimately associated with reflecting surfaces, *e.g.* circuit elements on the surface of a silicon substrate. It is known that the precision with which such measurements can be made depends upon extremely accurate focusing of the microscope. The usual focusing criterion of optimum image sharpness is often insufficiently precise, and tends to prove fatiguing over extended periods.

The invention, in preferred embodiments, aims to circumvent this difficulty by a novel form of instrumentation which exploits the principle of distance location by detection of the precise point of intersection of two mutually inclined beams of light. For example, in optical range-finding, distance is determined by changing the angular inclination of two beams until the identical images they bear are seen to coincide. In the present invention, this angular inclination is kept constant, and, for example, the distance between a microscope objective and an object surface is adjusted (focused) to bring corresponding images of a target pattern into coincidence.

According to one aspect of the present invention, there is provided optical viewing apparatus provided with a focusing arrangement, comprising means for providing two beams of light, mutually inclined at a fixed angle, means for converging said beams of light in the vicinity of a reflective viewed surface, and means for adjusting the relative distance between said apparatus and said surface until said beams coincide at said surface.

According to another aspect of the present invention, there is provided a method of focusing optical viewing apparatus, comprising the steps of converging two beams of light, mutually inclined at a fixed angle, in the vicinity of a reflective viewed surface, and adjusting the relative distance between the apparatus and said surface until said beams coincide at said surface.

The accompanying diagrammatic drawings illustrate preferred arrangements of optical imaging apparatus according to the invention in which:

Figure 1 is a diagrammatic illustration of a first embodiment of microscope;

Figure 2 is a diagrammatic illustration of an alternative construction for part of the microscope shown in Figure 1; and

Figure 3 is a diagrammatic illustration of a further modification to the construction of microscope shown in Figure 1.

The invention will now be described in detail, by way of example only, with reference to optical viewing apparatus in the form of a microscope, though it should be understood that the invention is applicable generally to optical viewing apparatus. Only those microscope parts necessary to the understanding of the invention have been shown.

Referring now to Figure 1 of the drawings, a lens 12 images a lamp condenser 10 into the vicinity of a special prism assembly 5 arranged at a fieldilluminating plane. In this particular version of the invention, the assembly 5 consists of a base prism 14 and a semi-circular prism 16 having about twice the angle of the base prism 14. 15 is an opaque fiducial line on the base prism 14. The assembly 5 is shown in an inset in the Figure.

It will be noted from the drawing that the prism assembly, formed by prisms 14 and 16, is arranged with the incident surface of the prism 16 perpendicular to the optical axis of the apparatus and directly in the path of an incident light beam 11.

Also, the prisms 14 and 16 are coupled together with their adjacent surfaces as close together as possible, in order to minimise ray separation in the vicinity of the fiducial line 15 and thereby provide sharpest possible focusing of the fiducial line 15.

On its way to the assembly 5, light beam 11 passes through a specially provided aperture diaphragm 13, which is subsequently imaged into the plane of the microscope's conventional aperture iris diaphragm 19 by lenses 17 and 18. However, the prism assembly 5 splits the beam into two divergent light beams so that the respective images of the aperture diaphragm 13 formed in the plane of the diaphragm 19 are laterally displaced from the instrument axis in opposite directions. These two virtual illuminating apertures are imaged into the vicinity of the microscope's objective lens 23 by lens 21, *via* a field diaphragm 20 and a conventional beam-splitting plate 22.

The fiducial line 15 is focused upon the viewed specimen surface 24 by the objective lens 23 when the microscope focus is correct, for which purpose the microscope is accurately calibrated. The two images of the line then fuse into a single line, as indicated by the full horizontal line of the figure inset. However, it can be seen that if the surface is moved to 24*a*, then the images of the fiducial line will separate by a transverse distance d and the line will appear as shown by the two dashed lines in the figure inset. As shown in the diagram, $d=2\ s \tan \text{arc sine}\ (NA/2)$ where s is the amount of defocus along the instrument axis and NA is the microsope objective's numerical aperture. It is assumed that the centre line of each beam is inclined at an angle corresponding to half the objective's numerical aperture, but this is in no way essential to the invention.

In practice, the separation d is doubled by virtue of reflection at the specimen surface 24, provided that the latter is substantially specular,

i.e. virtually a mirror. The image may be viewed through an eyepiece or T.V. camera (not shown).

It could be advantageous to replace the single fiducial line with a plurality of lines so that focus settings could be made at more than one point in the microscope field.

In a preferred embodiment the components 13, 14, 15 and 16 can be conveniently switched out of the optical path to permit easy return to conventional conditions. In practice, the components 12 to 18 can be provided as a module which can be removed from the path of the light beam 11, and replaced by a simple module which would contain a field lens equivalent to the single lens 18. In this manner, the lenses 17 and 18 can be provided as a doublet, each specially corrected. By providing the components 12 to 18 as a module, the advantage is obtained that an existing microscope may readily be converted to one as illustrated, simply by removing the field lens equivalent to the single lens 18, and securing the modular assembly of components 12 to 18 in place.

In the illustrated arrangement, it is particularly advantageous that the semi-circular prism 16 precedes the base prism 14. This arrangement minimises distortion of the fiducial line 15 provided on the base prism 14.

In an alternative arrangement to that illustrated, the diaphragm 13 may be provided with two apertures, to provide two light beams which are then mutually diverted at a fixed angle by suitable means. Such apertures in the diaphragm 13 are preferably separate, but could conceivably merge, such that there is a slight degree of overlap between the two light beams.

In the illustrated embodiment, a fiducial line 15 is provided, to enable coincidence of the two light beams at the specimen surface 24 to be detected. As an alternative, the light beams may be provided as well defined light pencils, for example, of which coincidence is detected at a specimen surface 24. However, such an arrangement is unlikely to give the degree of accuracy necessary in microscopic measuring devices, although it may find application in optical viewing apparatus generally.

Referring now to Figure 2 of the drawings, there is shown an alternative construction for part of the microscope shown in Figure 1. The optical axis is designated by reference numeral 30, and a light beam 31 issues from a light source and passes through an aperture diaphragm 32 having an aperture 33 which is offset from the optical axis 30. The light beam 31 is incident upon a double refracting crystal 34 which is arranged to produce, from the light beam 31, two orthogonally polarised virtual images from the aperture 33. Two polarised light beams 35 and 36 issue from the crystal 34, the beams 35 and 36 being polarised in directions at right angles to each other. A lens 37 is arranged to focus the light beams 35 and 36 onto a field illuminating plane at which is located a double selector plate 38. The double selector plate 36 comprises a pair of selector plates 39 and 40, and a fiducial line 41 is arranged at the interface between the plates 39 and 40. The double selector plate 38 is arranged to convert the polarised light beams 35 and 36 into two diverging light beams 42 and 43 respectively which are polarised in the same direction. The light beams 42 and 43 then pass through a double lens arrangement 44, 45 which converge the light beams 42 and 43 into parallel rays 46 and 47 which are incident upon beam-splitting plate 22, which then directs the rays towards the objective lens and the reflective viewing surface (not shown) in similar manner to that as shown in Figure 1.

The double selector plate 38 is shown in more detail, in plan view, inset to Figure 2, and consists of a birefringent half wave retardation plate 39 followed by a polarising plate 40. The diagonal hatching of plate 39 indicates that its extinction directions are diagonally orientated relative to the orthogonally polarised beams 35 and 36, and that it intercepts only a portion of the field illuminating aperture. The half wave plate 38 therefore rotates the vibration directions of the beams 35 and 36 through 90°, so that beam 36 is subsequently extinguished by the polarising plate 40 by virtue of the vibration direction of the latter being horizontally orientated (as indicated by hatching). Thus, only beam 35 finally emerges from the region of the selector plate 38 intercepted by the half wave plate 39. On the other hand, the remaining region of the polarising plate 40, not preceded by plate 39, extinguishers beam 35 so that only beam 36 emerges from this region, thereby achieving by different means the effect illustrated by the prismatic assembly 5 shown in Figure 1.

If desired, a similar selective effect may be achieved by replacing plates 40 and 39 with a pair of mutually crossed polarising plates, similar to bipolar plate 56, which is described in more detail below with reference to Figure 3. However, it is considered that such an arrangement may involve some difficulty in achieving a sufficiently perfect abutting boundary between the two semi-plates.

Accordingly, the plates 39 and 40 suppress the unwanted alternate components in the polarised light beams 35 and 36, so as to provide the unipolarised light beams 42 and 43.

Referring now to Figure 3 of the drawings, there is shown a further modification to the construction of the microscope shown in Figure 1, having another arrangement for providing the two light beams which are mutually inclined to each other at a fixed acute angle. The arrangement comprises a double aperture diaphragm plate 50 having a pair of apertures 51 and 52 arranged one on either side of the optical axis 53 in order to form a pair of parallel light beams 54 and 55, when a light source (not shown) illuminates the plate 50. A bipolar plate 56 is arranged in the path of the light beams 54 and 55 so as to form two orthogonally polarised light beams 57 and 58. The polarised light beams 57 and 58 are

focussed at a field-illuminating plane by means of a lens 59, there being provided at the field illuminating plane a selector plate 38 which is similar to that described above with reference to Figure 2. The double selector plate 38 converts the polarised light beams 57 and 58 into unipolarised light beams 42 and 43, in similar manner to that described above with reference to Figure 2, which then pass on through a lens assembly to the beam splitting plate, objective lens and reflective viewing surface (not shown).

Thus, as will be apparent from the above description of the preferred embodiments, the invention provides an optical imaging apparatus comprising a reflective viewed surface, an objective lens capable of being focussed upon said reflective surface, a fieldilluminating plane located at a long conjugate of the objective lens, means for producing at least two light beams which diverge mutually at an acute angle in a given plane from different localised regions of the field-illuminating plane, at least one fiducial line provided at the field-illuminating plane and extending transversely of the plane of divergence of the light beams, and means for adjusting the relative distance between the objective lens and the reflective surface in order to render the images of the fiducial line formed by the objective lens uniquely co-linear at a short conjugate of the objective lens in the vicinity of the reflective surface.

Claims

1. Optical viewing apparatus provided with a focusing arrangement and comprising:
means for providing two beams of light which are mutually inclined at a fixed angle;-
means for converging said beams of light in the vicinity of a reflective viewed surface; and
means for adjusting the relative distance between the apparatus and said surface until said beams coincide at said surface.

2. An optical imaging apparatus comprising an objective lens capable of being focussed upon a reflective viewed surface, a field-illuminating plane located at a long conjugate of said objective lens, means for producing at least two light beams which diverge mutually at a acute angle in a given plane from different localised regions of said field illuminating plane, at least one fiducial line provided at said field illuminating plane and extending transversely of the plane of divergence of said light beams, and means for adjusting the relative distance between said objective lens and said reflective surface in order to render the images of said fiducial line formed by the objective lens uniquely colinear at a short conjugate of the objective lens in the vicinity of said reflective surface.

3. Apparatus according to claim 2, including a prism assembly arranged at said field-illuminating plane to split an incident light beam so as to provide said two beams of light.

4. Apparatus according to claim 3, in which said prism assembly includes a prism provided with said fiducial line.

5. Apparatus according to claim 3, in which said prism assembly comprises a double prism assembly.

6. Apparatus according to claim 5, in which one of said prisms is arranged with its incident surface perpendicular to, and directly in the path of said incident light beam.

7. Apparatus according to claim 6, in which said fiducial line is provided on the other of said prisms.

8. Apparatus according to any one of the preceding claims, in which said means for providing said two beams of light comprises an aperture diaphragm and a double prism assembly arranged consecutively along the optical axis of the apparatus and movable bodily together into and out of the path of an incident light beam.

9. Apparatus according to any one of the preceding claims, including a modular assembly removably arranged along the optical axis of the diaphragm and comprising a lens, an aperture diaphragm, a double prism assembly and a doublet which are arranged to convert a single incident light beam into said two mutually inclined beams of light.

10. Apparatus according to claim 9, in which said aperture diaphragm has two apertures.

11. Apparatus according to any one of the preceding claims and comprising a microscope.

12. Apparatus according to claim 2, in which said means for producing at least two light beams comprises an aperture diaphragm, a double-refracting crystal for producing two orthogonally polarised virtual images of said aperture, a lens for focusing the polarised light beams at said field-illuminating plane, and a selector plate provided with said fiducial line and arranged at said field-illuminating plane for converting the polarised light beams into said two divergent light beams.

13. Apparatus according to claim 2, in which said means for producing at least two light beams comprises a double aperture diaphragm plate for producing two parallel light beams, a bipolar plate for producing two orthogonally polarised light beams, a lens for focusing the polarised light beams onto said field illuminating plane, and a selector plate arranged at said field illuminating plane for converting the polarised light beams into said two divergent light beams.

14. A method of focusing an optical viewing apparatus, comprising converging two beams of light, which are mutually inclined at a fixed angle, in the vicinity of a reflective viewed surface, and adjusting the relative distance between the apparatus and said reflective surface until said beams coincide at said surface.

15. Apparatus according to claim 1 and substantially as hereinbefore described with reference to any one of the embodiments illustrated in the accompanying drawings.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1981. Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.